FLEXURAL ANALYSIS OF CONCRETE BEAMS LONGITUDINALLY REINFORCED WITH GFRP BARS USING DISCRETE ELEMENT MODEL

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Especially for my beloved husband, my dearest mother, my late father and my family, all of you are the special part that cherished my heart.

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ABSTRACT

This paper presents experimental and analytical study related to the flexural behavior of concrete beams longitudinally reinforced with GFRP bars. The specimens consist of simply supported reinforced concrete beams with two point load. Totally 16 concrete beams includes 8 beams reinforced with steel and 8 beams reinforced with GFRP bars were tested to failure. Flexural capacity of the beam was observed experimentally and analytically. A computer program of cross sectional analysis using discrete element model was developed in this study to determine the flexural capacity of the beams. In addition, available stress-strain model proposed by the other researchers was used in order to simulate the behavior of material in calculation process. Finally, the flexural capacity obtained from analytical calculation was compared to that obtained from the test in term of moment-curvature curves and load deflection curves. The results show that beam reinforced with GFRP experienced larger ultimate load and larger deflection at same load level compared to beam reinforced with steel.

Keyword: Reinforced concrete beams, Glass Fiber Reinforced Polymer (GFRP), Flexural capacity.

ABSTRAK

Laporan ini memaparkan ujikaji makmal dan analisis mengenai sifat lenturan rasuk konkrit yang bertetulangkan polimer bertetulang gentian kaca (PBGK). Spesimen ialah rasuk disokong mudah yang dikaji melalui ujian beban dua titik. Kesemua 16 buah rasuk termasuk 8 buah rasuk bertetulang keluli dan 8 buah rasuk bertetulang PBGK diuji sehingga gagal. Kapasiti lenturan rasuk kemudian diperhatikan melalui ujikaji dan analisis. Perisian computer menggunakan unsur diskrit dibangunkan dalam kajian ini untuk menentukan kapasiti lenturan rasuk. Selain itu, model tegasan-terikan oleh penyelidik lain digunakan untuk simulasi perilaku bahan dalam proses pengiraan. Akhirnya, kapasiti lenturan yang diperolehi dari analisis dibandingkan dengan yang diperolehi dari ujikaji melalui graf momen-lengkungan dan beban-defleksi. Keputusan menunjukkan pada beban yang sama rasuk yang bertetulangkan PBGK mengalami defleksi lebih besar dan memikul beban maksimum yang lebih besar.

Kata kunci: Rasuk konkrit bertetulang, Polimer Gentian Bertetulang Kaca (PBGK), Kapasiti lenturan.

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CHAPTER I

INTRODUCTION

1.1 Introduction

Reinforced concrete is a strong and durable building material that can be formed into various shapes and sizes. Its utility and versatility are achieved by combining the best features of concrete and steel reinforcement. When the concrete are combined together with steel, the steel is able to provide the tensile strength while the concrete which is strong in compression protects the steel to give durability.

In current time in Malaysia, as the demand of steel is higher than production itself making the rule of supply and demand applies and led to the rise of its price. The steel is also has problem regarding corrosion. The usage of fiber reinforced polymer (FRP) composite for concrete applications is relatively a new technology that has a potential to replace the traditional steel reinforcement in construction industry as it has the advantages such as not subjected to corrosion, high tensile strength and low unit weight. But since the mechanical properties and surface deformation of FRP bars are different from the conventional steel reinforcement used, investigation is needed to study the behavior of structures using FRP. This study will focus on investigating the flexural behavior of beams reinforced with FRP to see the material's ability to resist deformation under static monotonic load.

1.2 Problem Statement

Steel bars have been used as reinforcement for more than 100 years and performed well when combined together with concrete structure. The performance of the reinforcement anyhow will change when it is exposed to aggressive environments such as in watery area. As we know, one of the problems faced in construction industry is the use of steel in construction as it is subjected to rust and leads to corrosion.

The construction technology now has become more and more advanced allowing the development of new technologies or material to replace the old one and also solved some of the problems faced by construction experts. The fiber reinforced polymer (FRP) composite is an alternative to replace the current use of steel as it is rust proof and stronger in terms of stiffness compared to steel.

Since the flexural strength normally control the stiffness of beams, more study is still needed related to the flexural behavior of concrete beam reinforced with FRP as it has different properties from steel.

1.3 Objectives

The objectives of this study are to:

1. To study the flexural behavior of concrete beam reinforced with GFRP bars and compared with beam reinforced with steel.
2. To observe the effect of longitudinal reinforcement ratio, shear reinforcement ratio, and shear span-effective depth ratio to flexural behavior of the beams.
3. To create an analytical model that can predict the flexural behavior of the beams.

1.4 Scope of Study

This study is done to analyze the flexural behavior of concrete beams reinforced with steel and GFRP under static monotonic loading. This study involves laboratory activities, analytical study and flexural analysis. Through laboratory activities, sixteen beams are tested under static monotonic loading until failure. The beams are then analyzed by numerical methods using FORTRAN language. A series of cross sectional analysis using discrete element model was developed in this study. In addition, available stress-strain model proposed by the other researchers was used in order to simulate the behavior of material in calculation process. The results of experimental, analytical and flexural analysis prediction will be summarized in terms of load versus strain, load versus deflection and moment versus curvature curves.

CHAPTER II

LITERATURE REVIEW

2.1 Reinforcement

Reinforcements are a tensioning device in a reinforced concrete structure used to hold concrete under compression. Steel is commonly used as reinforcement bars but this project will also focus on using Fiber Reinforced Polymer (FRP) as reinforcements. By adding such reinforcements, it can:

1. Improve formability
2. Increase strength to density and stiffness to density ratio
3. Increase resistance to corrosion, fatigue, creep and stress rupture
4. Reduce coefficient of thermal expansion
5. Produce higher temperature performance

2.2 Fiber Reinforced Concrete

Fiber reinforced concrete is concrete reinforced with fiber reinforcement. The fibers used can be made from plastic, glass and many other materials. The fiber reinforced concrete become popular in recent years because the resulting concretes are substantially tougher and has greater resistance to cracking and higher impact resistance.

The use of fiber reinforced concrete does significantly increase the initial costs, but in the long run it is cost effective as it increased the service life.

2.3 Fiber Reinforced Polymer (FRP)

Fiber Reinforced Polymer (FRP) can be considered as a fairly new material in construction industry, but its numerous advantages have made it very popular. FRP become popular because of some reasons such as stronger than steel, superior corrosion resistance, low unit weight and good fatigue behavior. FRP is also magnetically neutral and makes it become very attractive especially in construction of hospital and airport floor areas, which often require magnetic-free environment. (Thamrin, R., *et. al.*, 2002).

In general, FRP can be classified as composite materials that combine a polymer with reinforcing agents. The polymer matrix can be either thermoplastic resin such as polyester, isopolyester, vinyl ester, epoxy and phenolic that reinforced with fibers such as glass, carbon, aramid or other reinforcing materials. FRP may also contain fillers, additives and core materials added to modify and enhance the final product for structural application.

It is important to study the composition of FRP and their characteristics because it will influence their mechanical properties and performance. Criteria that should be considered in the study include:

1. Type of reinforcement or fiber
2. Percentage of fiber volume by weight
3. Orientation of fiber
4. Type of resin
5. Service conditions

The most common FRP composites use in construction industry contain fibers made of aramid (AFRP), carbon (CFRP) and glass (GFRP). However, this study will focus on using GFRP as the reinforcement bars.

2.4 Glass Fiber Reinforced Polymer (GFRP)

Hollaway, L. (1993) stated that glass fibers is the common name given to a number of mutually soluble oxides which can be cooled below their true melting point without crystallization taking place. They are clear, amorphous solids and fail with typical conchoidal fracture surfaces.

Glass is an amorphous material obtained by super cooling of molten glass. They are produced by the combination of metallic oxide with silica in a chemical reaction. E-glass which is based on alumina-lime-borosilicate composition is extensively used since they are more economic, good chemical resistance, high insulating properties and well-performed in mechanical properties. Another commercial type of glass fiber is S-glass which has higher strength, heat resistance and modulus. S-glass normally being applied in the aerospace industry, which has about one-third stronger than E-glass and composed of 65 % silicon dioxide, 25 % aluminum oxide and 10 % magnesium oxide. (James, A. J., and Thomas, F. K., 1985).

In comparison, glass is generally good in the impact resistance, but higher in weight compare to carbon and aramid. It has an equal or better than the steel in certain forms of characteristics. However, the lower modulus made it need a special design in order to perform well in its applications. Glass Fiber Reinforced Polymer (GFRP) is widely used in the construction and automobile industries. For examples, highway sign and post, manhole cover, aesthetic building structures and commercial roofing. As proven, bridge columns that were wrapped with the GFRP were not shaken during earthquake (Dominick, V. R., 1997).

2.5 History of Glass Fiber Reinforced Polymer (GFRP)

According to Davis, C., the first product manufactured from GFRP was a boat hull, which was manufactured in 1930s using a mould made of foam. One of the most notable GFRP projects ever was completed during the 1950s. The Massachusetts Institute of Technology completed a design of a house that was crafted entirely from GFRP. The carefully designed GFRP house began being constructed in 1956 in the Tomorrowland section of Disneyland. Disney's GFRP house was a popular attraction for a full decade before being destroyed in 1967. After the demolition, the building industry began to employ GFRP in a wider variety of construction applications.

By 1994, the building industry had used almost 600 million tons of architectural fiberglasses to craft a variety of buildings and elements. Its usefulness in repairing and renovating structures and elements crafted from an assortment of material was also recognized. Today, there are numerous companies that specialize in the production of GFRP products. These businesses routinely use GFRP to produce watertight domes, detail sculptures and durable benches. GFRP can also be finished to look like wood, quarried stone and bronze. So, individuals can enjoy the beauty of these more traditional materials without the associated maintenance, added weight and higher price tag.

2.6 Research on Glass Fiber Reinforced Polymer (GFRP)

Studies carried out by other researchers have been conducted related to the application of GFRP rods as reinforcement in reinforced concrete structures. Most of them focused on studying deflection behavior, cracking, bond characteristic and design of reinforced concrete beams using experimental investigation and analytical computation.

Experimental and analytical study was conducted by Thamrin, R., *et al.* (2002) on reinforced concrete beams with FRP rods tested until failure under monotonic loading. The tests were performed on three beams with carbon FRP and one beam with Glass FRP. The results show that flexural capacity of beam using carbon FRP is higher than beam using glass FRP.

Test conducted by Saadatmanesh, H., and Ehsani, M. R. (1991) involves an experimental study for six beams reinforced with different combination of GFRP and steel bars. The results showed that the GFRP bar has a good bond behavior with concrete and they concluded that the used of GFRP bars in reinforced concrete has a great chance to replace steel bars especially in corroded area.

Two simply and three continuously supported concrete beams reinforced with GFRP were tested by Habeeb, M. N., and Ashour, A. F. (2008). The experimental results revealed that over-reinforcing the bottom layer of either the simply supported or continuously supported GFRP beams is a key factor in controlling the width and propagation of cracks, enhancing the load capacity and reducing the deflection.

The load-deflection behavior of eight concrete beams reinforced with hybrid GFRP and steel bars were experimentally and theoretically investigated by Qu, W. J., *et al*. (2009). Comparisons between the experimental results and the predictions from theoretical analysis showed that the models adopted could predict the load carrying capacity, deflection and crack width.

MARC software was used in a numerical study done by Chiew, S. P., *et al.* (2007) to test ten beams strengthened by GFRP. The test was done investigate the flexural behavior of the beams under monotonic load. The experimental results showed that both flexural strength and stiffness of reinforced concrete beams could be increased by such a bonding technique.

A test was conducted by Mohd. Sam, A. R., and Narayan Swamy, R. (2005) on beams strengthened with GFRP to analyze their load carrying capacity, load-deflection, load-concrete strain, load-reinforcement strain, cracking and mode of failure. The experimental results shows that beam reinforced with GFRP bars experienced lower ultimate load, lower stiffness and larger deformation. However, the performance of GFRP beams improved when stainless steel was used as shear reinforcement.

2.7 Stress-Strain Behavior

The strength and stiffness behaviors are dominated by the directional characteristic of fibers and the interaction between the stiff fibers and weaker polymer matrix. Different with the steel which has yield point before failure, FRP do not display yield point except for the AFRP stressed in compression, which is a special case. The stress-strain behavior of the FRP until failure is almost linear as shown in Figure 2.1. Elongation at break is typically a few percent for the GFRP and may reach until 5-10 % for the advanced FRP composites (Dominick, V. R., 1997).

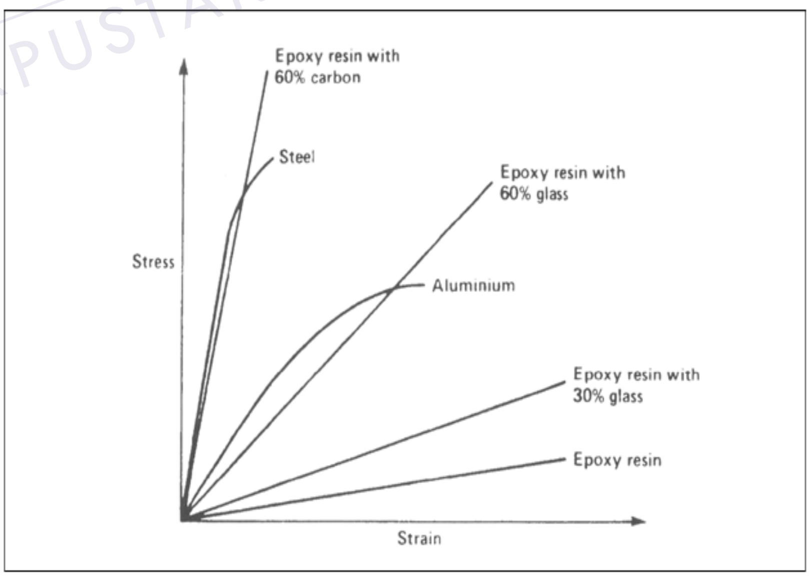

Figure 2.1: Stress Strain Behavior of FRP
(Dominick, V. R., 1997)

2.8 Flexural Analysis

Through this project, flexural capacity of beams under monotonic load is investigated. The load on the beams is gradually increased until peak load and caused flexural failure.

At a low load, the tensile strains and stresses is below the concrete tensile strength the beam is uncracked. As the load is increased, the tensile stress in concrete reaches the tension strength and developed cracks. When the load on the flexural members is further increased the concrete strain reaches the limiting value and represents crush of concrete as flexural failure happened. Flexural failure in a beam can occur in two different ways:

1. The reinforcement yields before the concrete reaches its limiting strain in compression. This type of failure is preceded by warnings through increase of deflection and cracks.

2. Concrete compressive strain reaches the crushing strain before the reinforcement starts to yield. This results in crushing of concrete without warnings.

2.9 Discrete Element Method

Nowadays, discrete element method is becoming widely accepted as a method for addressing engineering problems. The use of discrete element method to solve engineering problems starts in the early of 1970s focusing on rock and soil mechanics disciplines. The discrete element method has become an approach for numerical simulation of engineering applications with most approaches to geological and rock engineering problems.

REFERENCES

Thamrin, R., Kaku, T., and Imai, T. (2002). *Flexural and Bond Behavior of Reinforced Concrete Beam with FRP Rods*. Proceeding of Engineering Theoretical Mechanics 2002, Bali, Indonesia, Page 469-478.

Hollaway, L., (1993). *Polymer Composites for Civil and Structural Engineering (1ST Edition)*. Blackie Academic & Professional.

Saadatmanesh, H., and Ehsani, M. R. (1991). *Fiber Composite Bar for Reinforced Concrete Construction.* Journal of Composite Materials, Vol. 25, Page 188-203.

Habeeb, M.N., and Ashour, A. F. (2008). *Flexural Behavior of Continuous GFRP Reinforced Concrete Beams*. Journal of Composites for Construction-ASCE, March-April 2008, Page 115-123.

Qu, W. J., Zhang, X. L., and Huang, H. Q. (2009). *Flexural Behavior of Concrete Beams Reinforced with Hybrid (GFRP and Steel) Bars*. Journal of Composites for Construction-ASCE, September-October 2009, Page 350-359.

Chiew, S. P., Sun, Q., and Yu, Y. (2007). *Flexural Strength of RC Beams with GFRP Laminates.* Journal of Composites for Construction-ASCE, September-October 2007, Page 497-506.

Mohd. Sam, A. R., and Narayan Swamy, R. (2005). *Flexural Behavior of Concrete Beams Reinforced with Glass Fiber Reinforced Polymer Bars*. Jurnal Kejuruteraan Awam 17(1), Page 49-57.

Finch, E., Hardy, S., and Gawthorpe, R. (2003). *Discrete Element Modelling of Contractional Fault-Propagation Folding Above Rigid Basement Fault Blocks.* Journal of Structural Geology, Page 515-528.

Lorig, L. J., and Hobbs, B. E. (1990). *Numerical Modeling of Slip Instability Using the Distinct Element Method with State Variable Friction Laws.* International Journal of Rock Mechanics and Mining Science and Geomechanics Abstracts, Page 525-534.

Brady, B. H. G., Lemos, J. V., and Cundall, P. A. (1986). *Stress Measurement Schemes for Jointed and Fractured Rock*. Proceeding International Symposium on Rock Stress and Rock Stress Measurements, Stockholm, Page 167-176.

Davis, C. *Glass Fiber Reinforced Polymer - A Brief History*. http://ezinarticles.com

Macgregor, J. G., and Wight, J. K. (2005). *Reinforced Concrete – Mechanics and Design (4TH Edition).* Prentice Hall.

McCormac, J. C., and Nelson, J. K. (2005). *Design of Reinforced Concrete (6TH Edition).* John Wiley & Sons Inc.

Almusallam, T. H., (1997). *Analytical Prediction of Flexural Behavior of Concrete Beams Reinforced by FRP Bars*, Journal of Composite Material, Vol. 31, Page 640-657.

Dominick, V. R., (1997). *Design with Reinforced Composites: Technology Performances – Economics*. Munich Vienna New York: Hanser Publisher.

Tahir, W., Abdul Wahid, M., Abu Bakar, A. A., and Ong, B. K., (2005). *Fortran 77 Application: Civil Engineering Problem Solving.* Universiti Teknologi MARA.

James, A. J., and Thomas, F. K., (1985). *Engineering Materials Technology – Structures, Processing, Properties and Selection (Fourth Edition).* Prentice Hall.